

PHOTOELECTRIC CONVERSION DEVICE,  
RADIATION DETECTION APPARATUS, IMAGE PROCESSING  
SYSTEM, AND DRIVING METHOD THEREOF

5 BACKGROUND OF THE INVENTION

Field of the invention

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T0520.919T560

The present invention relates to a photoelectric  
conversion device, particularly, a photoelectric  
conversion device for office appliances such as a  
10 copying machine, a facsimile, a scanner, or the like  
and a photoelectric conversion device to be used for an  
x-ray camera tube apparatus for medical use to be used  
for diagnosis or to be used for nondestructive  
inspection apparatus; an image processing (image  
15 information or image data processing) system; and their  
driving method.

Related Background Art

Conventionally, x-ray direct radiography has been  
carried out by so-called a film way, which has been a  
20 main stream method carried out by radiating x-rays to a  
patient and transferring the transmitted x-rays to a  
photosensitive film through a visible light conversion  
phosphors. The film way has problems that it takes a  
long time from photographing to developing processes  
25 and that it requires to store and search immense  
photographed films in terms of maintenance and  
management in a hospital.

By the way, there is another way available using extremely bright phosphors in place of the film which is carried out by storing an x-ray image of a patient in the extremely bright phosphors, scanning the image with laser beam thereafter, and reading the x-ray image as digital values. If an image is converted to be digital, that makes recording in a variety of media possible, so that image storage, search, and transfer can easily be carried out to improve the efficiency in a hospital in terms of the maintenance and management. Further, obtaining image data as digital values makes highly advanced image processing by a computer possible and that is expected to result in improvement of diagnosis.

However, even the way using extremely bright phosphors has, as same as the film way, a problem that it takes a long time from photographing to developing.

On the other hand, an x-ray imaging apparatus using a solid imaging (image-pickup) device such as CCD and an amorphous silicon semiconductor has been proposed. As same as the film way, it is carried out by directly converting an x-ray image of a patient obtained through a visible conversion type phosphors by x-ray radiation to an digital image approximately at real time by a large number of imaging (image-pickup) elements arranged in a two-dimensional array and reading the image. Since the digital image can

obtained approximately at real time, as compared with the above described film way and the way using the extremely bright phosphors, it is greatly advantageous. Especially, since amorphous silicon can be formed in a large surface area, in the case of an x-ray imaging apparatus using such an amorphous silicon, photographing (image-pickup) of a large portion such as chest photography can be carried out in equal size. Consequently, a high light utilization factor is provided and a high S/N ratio is expected.

However, in an x-ray imaging apparatus for medical use, in order to photograph a chest of a human being in equal size, it is required to make available a solid imaging device with a large surface area as wide as 40 cm x 40 cm and the number of pixels is extremely as high as 5,000,000 to 10,000,000.

It is not so easy to produce the properties of these immense pixels all evenly and reliably. For example, in the case of using amorphous silicon for photoelectric conversion elements and switching elements for charge transfer, if continuous operation is carried out for a long duration, dark current of the photoelectric conversion elements will be increased and the properties of the switching elements will be changed. To deal with such cases, a countermeasure employed is that the photoelectric conversion elements and the switching elements are so designed as to be

operated only at the time of taking images and as to be inhibited from operation at the time of taking no image. For example, when no patient is in a photographing chamber, bias wires of the photoelectric conversion elements and gate wires and reading-out wires of the switching elements are biased to be zero potential and no electric field is applied to the insides of the amorphous elements to lower the property alteration of the elements in a long time use.

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10 However, this case has a complicated handling of operating the photoelectric conversion elements and switching elements after recognizing the presence of a patient near the imaging apparatus and then carrying out image pickup operation. In other words,

15 operationability of the apparatus is deteriorated. A design to automatically recognize the existence of a patient may also be possible, however it leads to the cost-up of an apparatus.

On the other hand, in the case where a large number of photoelectric conversion elements with a large surface area are fabricated using an amorphous silicon thin film, there are problems that traces of impurities mixed in fabrication processes and dangling bonds tend to be increased and that they form as defect levels. They work as trapping levels and become unnecessary dark current in the photoelectric conversion process to decrease the S/N ratio. As a

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driving method of a photoelectric conversion device in which the dark current is lessened, possible is a method of carrying out photoelectric conversion after the dark current is moderated by waiting for several to several 10 seconds from biasing the photoelectric conversion elements (and switching elements). However, if such a method is employed for an x-ray imaging apparatus, the cycle for taking a plurality of patients will become long.

As described above, in the photoelectric conversion device with a large surface area using amorphous silicon, it is made difficult to keep a high S/N ratio owing to the property alteration during a long time use and defect levels in a film and hence, a photoelectric conversion device and its driving method possible to be operated easily while keeping good S/N ratio have been expected to be developed.

#### SUMMARY OF THE INVENTION

An object of the present invention is to lower the property alteration during a long time use and the S/N ratio owing to dark current, shorten the imaging (image-pickup) cycles, and improve the operationability of a photoelectric conversion device, an image data processing system and their driving method.

A photoelectric conversion device of the present invention to solve the above described objects is a

photoelectric conversion device comprising: a  
photoelectric conversion substrate comprising a  
substrate and a plurality of photoelectric conversion  
elements arranged on the substrate; a light source; and  
5 an outer casing for housing these members, wherein,  
between a reading-out period for obtaining image data  
(image information) and a non-reading-out period in  
which reading-out is not carried out, the light source  
is turned on in the non-reading-out period.

10 Also, the present invention provides a  
photoelectric conversion device comprising a substrate  
equipped with a plurality of photoelectric conversion  
elements for photoelectrically converting incident  
light rays having the image data and light sources for  
15 radiating light rays having the foregoing image data  
and light rays having no image data to a plurality of  
the foregoing photoelectric conversion elements.

Further, the present invention provides an image  
data processing system comprising: a photoelectric  
20 conversion device comprising a substrate equipped with  
a plurality of photoelectric conversion elements for  
photoelectric conversion of incident light rays having  
the image data and a light source for radiating light  
rays bearing no image data to a plurality of the  
25 foregoing photoelectric conversion elements, a  
radiation source, and control means for independently  
controlling the foregoing radiation source and the

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foregoing photoelectric conversion device.

Further, the present invention provides an driving method of an imaging (image-pickup) apparatus, comprising first and second light sources and a semiconductor element comprising a semiconductor layer having an absorption region of the wavelength of the light rays radiated from the foregoing second light source, wherein the image data is read out by radiating light from the foregoing first light sources during the imaging (image-pickup) period and radiation by the foregoing second light sources is carried out during the non-imaging period.

Furthermore, the present invention provides a radiation detection apparatus comprising: a photoelectric conversion substrate comprising photoelectric conversion elements arranged on a substrate and an outer casing for housing the photoelectric conversion substrate, wherein the radiation detection apparatus is further provided with a light source in the outer casing and is further provided with a wavelength converter for reflecting the light rays from the light source and entering the reflected rays in the foregoing photoelectric conversion elements.

# BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a photoelectric conversion device of Embodiment 1 of the present invention;

5        FIG. 2 is a diagram of a circuit using a photoelectric conversion element of Embodiment 1 of the present invention;

FIG. 3 is a timing chart (1) of the circuit illustrated in FIG. 2;

10       FIG. 4 is a timing chart (2) of the circuit illustrated in FIG. 2;

FIG. 5 is a timing chart (3) of the circuit illustrated in FIG. 2;

15       FIG. 6 is a plan view of a photoelectric conversion element and a switching element shown in FIG. 1;

FIG. 7 is a cross-sectional view taken along the line 7-7 of FIG. 6;

20       FIG. 8 is a diagram of a two-dimensional electric circuit of the photoelectric conversion device shown in FIG. 1;

FIGS. 9A, 9B and 9C are band diagrams showing an operation of an MIS type photoelectric conversion element shown in FIG. 1;

25       FIG. 10 is a timing chart showing an operation of FIG. 8;

FIG. 11 is a cross-sectional view of a

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photoelectric conversion device of Embodiment 2 of the present invention;

FIG. 12 is a cross-sectional view of a photoelectric conversion device of Embodiment 3 of the present invention;

FIG. 13 is a cross-sectional view of a photoelectric conversion device of Embodiment 4 of the present invention;

FIG. 14 is a cross-sectional view of a photoelectric conversion device of Embodiment 5 of the present invention;

FIG. 15 is a cross-sectional view of a photoelectric conversion element of Embodiment 6 of the present invention;

FIG. 16 is a timing chart (1) of the circuit illustrated in FIG. 15;

FIG. 17 is a timing chart (2) of the circuit illustrated in FIG. 15;

FIG. 18 is a timing chart (3) of the circuit illustrated in FIG. 15; and

FIG. 19 is a block diagram of a photoelectric conversion device of Embodiment 7 of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the present invention will be described according to the drawings. The

radiation used in the present invention includes x-rays,  $\gamma$ -rays,  $\alpha$ -rays,  $\beta$ -rays, and the like.

(Embodiment 1)

FIG. 1 is a cross-sectional view of Embodiment 1 of a photoelectric conversion device according to the present invention. In the drawing, reference numeral 101 denotes a light ray source, 102 an object body to be read out, 103 a chassis, 104 a phosphor, 105 a photoelectric conversion element, 106 an insulating substrate, 107 a protective layer, and 108 an LED. This embodiment is performed by employing a photoelectric conversion device of the present invention for a radiation detection apparatus, especially, an x-ray imaging (image-pickup) apparatus.

In FIG. 1, the x-rays emitted out from the x-ray source 101 are radiated to the object body to be read out 102, the x-rays transmitted through the object body to be read out 102 reach the phosphors 104 and converted into visible light rays by the phosphors 104. The visible light rays from the phosphors 104 are photoelectrically converted in light-receiving faces of photoelectric conversion elements 105 arranged on an insulating substrate 106. The photoelectric conversion elements 105 are covered with the protective film 107 for the purpose of improving moisture resistance.

As the materials for the insulating substrate 106, usable is mainly transparent glass with a little amount

of alkaline components. The insulating substrate may be made of a plurality of insulating plates stuck to each other. Further, as the wavelength converter, phosphors are suitable to be used and as the materials for the phosphors, usable are  $Gd_2O_3:S:Tb$ ,  $CsI:Tl$  or the like.

On the other hand, the light rays (visible light rays) emitted out from the LED 108 installed under the insulating substrate 106 are transmitted through the insulating substrate 106 and after passing the side faces of the photoelectric conversion elements 105, the light rays are reflected by the phosphors 104 and radiated to the light-receiving faces of the photoelectric conversion elements 105. The phosphors 104 have different reflecting characteristics of light rays from the LED 108 depending on the materials, however any can be used unless the phosphors completely absorb light rays and any which emits light rays of several % to the photoelectric conversion elements 105 may be usable.

In FIG. 1, illustration is drawn as if the light rays from the LED 108 are perpendicularly radiated to the phosphors 104, however some light rays enter from diagonal direction and therefore, it is supposed that there are some components reflected by the phosphors 104 if those reflected by the mirror faces of the phosphor faces are included in the components.

In FIG. 1, the photoelectric conversion device of the present embodiment comprises the phosphors, the photoelectric conversion elements, LED or the like housed in an outer casing such as a chassis. The outer casing may be made of a material with extremely low x-ray absorption in the incident surface of x-rays and metals such as aluminum, a stainless steel or the like are suitable to be used owing to the economical cost and the high strength.

If the x-ray imaging apparatus employing the above described photoelectric conversion device is for a medical use, the object body to be read out is a patient (human body) and if the x-ray imaging apparatus is for non-destructive inspection, the object body to be inspected may be parts used for, for example, aircrafts and ships.

Further, FIG. 1 shows a cross-sectional view of the photoelectric conversion device, photoelectric conversion elements and LED are arranged in two-dimension in the depth direction of the surface of FIG. 1. Further, although being omitted in FIG. 1, switching elements may be arranged while being coupled with the photoelectric conversion elements in pairs on the insulating substrate.

FIG. 2 is a diagram of a signal detection circuit of a single photoelectric conversion element to be employed for the photoelectric conversion device

illustrated in FIG. 1. In the figure, the reference numeral 201 denotes an x-ray source, 202 a phosphor, 203 a photoelectric conversion element, and 204 an LED light source.

5 In FIG. 2, the photoelectric conversion element 203 is an MIS type photoelectric conversion element using an amorphous silicon semiconductor as a material. The MIS type photoelectric conversion element is constituted by stacking an insulating layer (insulator) and a semiconductor layer (semiconductor) on a lower part metal electrode layer (metal). Generally, an injection element layer (an n-type layer or a p-type layer) and an upper part electrode are arranged on the semiconductor layer. A detailed fabrication method and the operation principle of the MIS type photoelectric conversion element will be described later.

10 In FIG. 2, a power source for applying bias ( $V_s$ ) for photoelectric conversion, a power source ( $V_{REF}$ ) for resetting accumulated charges in the capacity of the MIS type photoelectric conversion element, and a ground point (GND) for applying zero bias ( $V_{GND}$ ) when no photoelectric conversion element is operated are connected to the MIS type photoelectric conversion element through SW1.

25 The x-rays emitted out the x-ray source 201 which is a first light source are radiated to an object body, which is not illustrated in FIG. 2 (a patient in the

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case of a hospital), and the transmitted x-rays collide with a wavelength converter.

In FIG. 2, the x-rays are converted into visible light rays by the phosphor 202 which is a wavelength converter. The visible light rays from the phosphor 202 are radiated to photoelectric conversion element 203. FIG. 2 shows an illustration only for one pixel, and the positioning correlation between the photoelectric conversion element 203 and the phosphor 202 is therefore not illustrated, however as being understood from FIG. 1, the image resolution property is improved by practically closely sticking both of them to each other. On the other hand, the visible light rays from the LED light source 204, which is a second light source, are radiated to the photoelectric conversion element 203 through another optical path different from the path for the x-rays. SW2 and SW3 are switches for turning on the x-ray source 201 and the LED light source 204, respectively.

FIG. 3 is a timing chart of operation in the circuit shown in FIG. 2 and shows the x-ray source, the LED light source, bias of the photoelectric conversion element, and the output of the photoelectric conversion element.

In FIG. 3, the x-ray source and the LED dare not to be turned on in order to show the state of dark output (dark current) of the photoelectric conversion

element. FIG. 3 shows the time chart of 6 cycles of (F1) to (F6).

In the cycle (F1), when bias potential is applied to the photoelectric conversion element, the dark  
5 current flows. Ideally, it is preferable for the dark current to be zero, however it is difficult to keep it zero. Further, a constant electric current does not flow simultaneously with the time when the electric power source is turned on, but it is high immediately  
10 after the turning on and gradually decays with the lapse of time.

As this cause, the following two are considered.

One is that in the case where photoelectric conversion elements are fabricated using an amorphous  
15 silicon semiconductor as a main material, defect levels are generally formed by dangling bonds in the amorphous semiconductor film and impurities mixed in fabrication process. They work as trap levels and immediately after the electric power source is turned on or even  
20 before the source is turned on, they trap electrons or holes and are thermally excited to a conduction band or a valence band after several milliseconds to several ten seconds and thus conduction current (dark current) flows. It is said that many trap levels exist  
25 especially in the interface portion between a semiconductor layer (an i-type layer) and an injection inhibiting layer (for example an n-type layer). In the

case where crystal type MIS photoelectric conversion elements are employed without using amorphous semiconductor films, it is said that the trap levels are not so many as those in case of using amorphous although they depend on the fabrication process conditions and the apparatus to be fabricated.

However, mismatch of crystal lattices is many in the interface portion between the semiconductor layer (an i-type layer) and the injection inhibiting layer (for example an n-type layer), and the trap level is not at zero. The photoelectric conversion elements tend to have an output of a photoelectric conversion element shown in FIG. 3.

The other cause is considered to be relevant to the property of the injection inhibiting layer. For example, in the case where the injection inhibiting layer is made of an n-type amorphous silicon, theoretically, holes are not injected to the semiconductor layer side. However, actually, in the case of particularly an amorphous layer, the n-type layer cannot completely block the holes. The holes injected to the semiconductor layer (i-type layer) through the n-type layer become dark current. The holes are accumulated in the interface between the semiconductor layer (i-type layer) and the insulating layer, and an the internal electric field in the i-type layer is moderated along with the accumulation of the



holes. Following the moderation of the electric field, the quantity of the holes injected from the n-type layer to the i-type layer is decreased, and therefore the dark current is decayed.

5           Signals with high S/N ratio can be obtained by waiting that the dark output of photoelectric conversion elements shown in FIG. 3 is sufficiently decayed. However, it takes a long time, several seconds to several ten seconds, until the dark output  
10 is decayed to an aiming level. In this case, for example, when the photoelectric conversion elements are employed for an x-ray imaging apparatus to be used in a hospital, the following procedure is required; a patient is guided to a photographing chamber, the  
15 photoelectric conversion elements are turned on, and after waiting for several to several ten seconds, the patient is subjected to x-ray exposure.

It is better to turn on the photoelectric conversion elements before a patient comes in the  
20 photographing chamber, however in that case, deterioration (property change, corrosion, or the like) of the photoelectric conversion elements is accelerated to make it difficult to provide an apparatus with a long life.

25           In an MIS type photoelectric conversion element, no electron and no hole pass the internal insulating layer, and the generated carriers are accumulated in

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the interface between the semiconductor layer and the insulating layer. In the case where the bias ( $V_s$ ) for photoelectric conversion shown in FIG. 2 is plus (+) bias, the accumulated carriers are holes and an n-type layer for inhibiting injection of the holes into the semiconductor layer is formed between the upper part electrode and the semiconductor layer. Electrons in the equal quantity of the hole carriers accumulated in the interface between the semiconductor layer and the insulating layer are supplied from the GND to the electrode side where ammeter is installed. The accumulated holes are either entirely or partially swept by controlling the bias of the sensor to  $V_{REF}$  in a short time. Generally, the potential of the  $V_{REF}$  is set lower than the potential of the  $V_s$ . In the timing chart of FIG. 3, the potential of  $V_{REF}$  is set to be the GND. In the cycle (F2), by applying the potential  $V_s$  again, dark current similar to that in the cycle (F1) flows.

At that time, the dark current becomes low as compared with that in the cycle (F1). That is supposedly attributed to that carriers relevant to the dark current and collected in the trap levels existing in the i-type layer, especially in the periphery of the interface to the insulating layer, are more lessened in the cycle (F2) than in the cycle (F1). Further, it is also supposedly attributed to that the holes

accumulated by the reset potential VREF of the cycle  
(F1) are not completely expelled and some remain in the  
semiconductor layer to consequently moderate the  
electric field in the inside of the semiconductor more  
5 in the cycle (F2) than in the cycle (F1).

In the same manner, as the cycles proceed from the  
cycle (F3) to the cycle (F6), the dark current is  
lowered and soon saturated. Nevertheless, although  
saturation takes place, since rush current flows at the  
10 time of switching the bias from the VREF to VS, the  
current value does not become a constant current value  
immediately after the switching. In the latter half  
even in one cycle, especially, immediately before  
switching to VREF, the current becomes constant without  
15 change with the lapse of time. In order to surely keep  
a high S/N ratio as an x-ray imaging apparatus, it is  
preferable that x-rays are radiated after the dark  
current is sufficiently reduced.

FIG. 4 is a timing chart obtained by radiating x-  
20 rays in the cycle (F6) after taking sufficient time.  
Since the properties of dark current in the cycle (F5)  
and in the cycle (F6) are approximately same, the  
steady part overlaid on the current output by the x-  
rays in the cycle (F6) can easily corrected by storing  
25 the output the cycle (F5) in a memory and then  
subjecting the subtraction processing thereafter.  
Incidentally, the output of the cycle (F7), which is

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not illustrated in FIG. 7, may be used.

Although depending on the properties of the dark current of the photoelectric conversion elements and the operation conditions of the apparatus, the period of each cycle of (F1) to (F6) takes generally 0.1 to 3 seconds. Supposing it is 2 second/cycle, it takes 12 seconds for 6 cycles. In other words, from the time when bias is turned on, it takes 10 seconds or more until x-ray photographing is carried out.

FIG. 5 is a timing chart obtained in the case of radiating x-rays and light rays from a light source.

During two operation periods, a reading-out period and a non-reading-out period, a first light source is turned on during the reading-out period, and a second light source is turned on during the non-reading out period. In the case of an x-ray imaging apparatus for medical use, the first light source is an x-ray source. In the case of a nondestructive inspection apparatus, the first light source is x-rays or another type of radiation. On the other hand, the second light source may be LED (light emitting diodes) and EL (electroluminescence), and any light source may be used as long as it has an electroluminescence wavelength in the wavelength region of light absorption of the photoelectric conversion elements.

The x-rays from the first light source, which is not illustrated, are the light rays to be radiated to

an object to be photographed in order to obtain image data of the object (the object to be photographed). The light rays from the second light source are not necessary to be radiated to the object (the object to be photographed) and it is sufficient for the light rays to reach the photoelectric conversion elements through any optical path.

In FIG. 5, the LED (the second light source) is turned on in the cycle (F2) and the x-ray source (the first light source) is turned on in the cycle (F3). In the example shown in FIG. 5, the cycle (F1) and the cycle (F2) are the non-reading-out period and the cycle (F3) is the reading-out period.

The photocurrent flowing owing to the light radiation by the LED is not read as an image signal. That is, the LED is lighted during the non-reading-out period, the cycle (F2).

Although the photocurrent flows owing to the light radiation by the LED, simultaneously with the turning-off of the light, the state that dark current is flowing can be restored. However, after the LED is turned off, as shown in FIG. 5, lower and more stabilized dark output (dark current) flows than the dark output (the dashed line) of the case where light rays of LED are not radiated in the cycle (F2).

That is attributed to that the photo energy of LED is absorbed in the semiconductor layer, the generated

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carriers are accumulated in the interface with the insulating layer, the inner electric field in the semiconductor layer is moderated, and the carriers flowing therein from the injection inhibiting layer are consequently decreased. In the next cycle (F3), as shown in FIG. 5, since the generated carriers by the LED light rays of the cycle (F2) cause effects of operating several cycles in dark state, the dark current is in stable state. Further, it is also possible to be supposed that the previously trapped electrons or holes relevant to the dark current are decreased by the light radiation.

If x-rays are radiated in such a low dark current state, signals with a high S/N ratio can be obtained.

In other words, if the dark current is lowered by radiating LED light rays before x-ray image-pickup (photographing), an x-ray image with a high S/N ratio can be obtained without requiring a long time to wait.

The radiation duration and the intensity of the light rays in the cycle (F3) in FIG. 5 are optional as long as they lower the dark current and may be, for example, approximately the dark current after the cycle (F6) in FIG. 3. By radiating x-rays in the cycle (F3) of the reading-out period, signals with a high S/N ratio can be obtained. Although it is not illustrated in the figure, if the signals of the cycle (F4) are taken in and subtracted from the x-ray outputs of the

cycle (F3), the fixed components in the dark current contained in the x-ray signals of the cycle (F3) can be corrected. As a result, if the dark current is lowered by radiating LED light rays before x-ray photographing,  
5 an x-ray image with a high S/N ratio can be obtained without requiring a long time to wait.

Although FIG. 5 is a timing chart where the cycle (F1) and the cycle (F2) are set to be the non-reading-out periods and the cycle (F3) is set to be the  
10 reading-out period, of course, it is also possible to radiate light rays by LED, which is the second light source, during the non-reading-out period in the cycle (F1) and to set the cycle (F2) to be the reading-out period. In that case, the time up to the x-ray  
15 radiation can further be shortened.

FIG. 6 shows the plan view of a photoelectric conversion substrate constituted using amorphous silicon semiconductor thin films for the photoelectric conversion elements and switching elements arranged on  
20 an insulating substrate shown in FIG. 1 and the wirings bonding these elements are also illustrated together. FIG. 7 shows the cross-sectional view taken along the line 7-7 shown in FIG. 6.

In FIG. 6 and FIG. 7, the photoelectric conversion  
25 elements 601 and the switching elements 602 (amorphous silicon TFT, hereinafter referred as to "TFT") are formed on the same photoelectric conversion substrate

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(insulating substrate) 603. The lower part electrode which is the first electrode layer of the photoelectric conversion element 601 and the lower part electrode (gate electrode) of the TFT 602 are commonly made of the same first metal thin film layer 604. The upper part electrode which is the second electrode layer of the photoelectric conversion element 601 and the upper part electrode (source electrode and drain electrode) of the TFT 602 are commonly made of the same second thin film layer 605. Further, the first and the second metal thin film layers used for the electrode layers 604 and 605, respectively, are commonly used for the wiring 606 for gate operation and the matrix signal wiring 607 of the photoelectric conversion circuit, respectively.

In FIG. 6, the number of pixels is  $2 \times 2$ , 4 pixels in total. The hatching part shown in FIG. 6 is a light-receiving faces of the photoelectric conversion elements 601. The reference numeral 609 denotes a power source line to apply bias to the photoelectric conversion elements. Further, the reference numeral 610 denotes a contact hole to connect a photoelectric conversion element 601 and the TFT 602. The light rays from the light source installed under the photoelectric conversion substrate 603 are led to the side of the phosphor 616 in the surrounding of the photoelectric conversion elements 601 from a region where the first



metal thin film layer 604 and the second metal thin film layer 605 do not exist. Light rays are shielded by the first metal thin film layer 604 immediately under the photoelectric conversion element 601.

5           Next, the fabrication method for fabricating a circuit part of a photoelectric conversion device of this embodiment will be described.

FIG. 7 is a cross-sectional view taken along the line 7-7 shown in FIG. 6 showing the plan view of the photoelectric conversion substrate.

10           In FIG. 7, chromium (Cr) is deposited in a thickness of 50 nm as a first metal thin film layer 604 on an insulating substrate 603 by a sputtering method and a resistance heating method and patterned by photolithographic patterning and the unnecessary areas are removed by etching. The first metal thin film layer 604 becomes a lower part electrode of a photoelectric conversion element 601 and a gate electrode of a switching element 602. Next, an a-SiN<sub>x</sub> layer (611), an a-Si:H layer (612) and an n<sup>+</sup>-layer (613) are successively formed in 300 nm, 500 nm, and 100 nm film thickness, respectively, in the same vacuum atmosphere by a CVD method. The respective layers 611 to 613 are respectively an insulating layer/a photoelectric conversion semiconductor layer/a hole injection inhibiting layer of a photoelectric conversion element 601 and respectively become a gate

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insulating film/a semiconductor layer/an ohmic contact layer of a switching element 602 (TFT). They are also used as an insulating layer in a crossing part (614 in FIG. 6) of the first metal thin film layer 604 and the second metal thin film layer 605. The film thickness of each of the layers 611 to 613 is not restricted to the above described thickness and may be properly designed depending on the voltage and the electric charge employed for a photoelectric conversion device and the incident light intensity of the light-receiving faces of the photoelectric conversion elements. At least, the thickness of the a-SiN<sub>x</sub> layer 611 is preferably 50 nm or more so as to inhibit both electrons and holes from passing through and sufficiently function as a gate insulating film of a TFT.

After the respective layers 611 to 613 are deposited, areas which become contact holes (610 in FIG. 6) are dry-etched by RIE, CDE or the like and after that, aluminum (Al) as the second metal thin film layer 605 is deposited in about 1,000 nm by a sputtering method or a resistance heating method. Further, patterning is carried out by photolithography and the unnecessary areas are removed by etching. The second metal thin film layer 605 becomes an upper part electrode of a photoelectric conversion element 601 and a source and a drain electrodes of a switching TFT 602

and other wirings. Further, simultaneously with the film formation of the second metal thin film layer 605, the upper and the lower metal thin films are connected through the contact hole parts 610. Further, in order to form a channel part of the TFT 602, a part between the source electrode and the drain electrode is etched by RIE method and after that unnecessary parts of the a-SiN<sub>x</sub> layer, the a-Si:H layer and the n<sup>+</sup>-layer are etched by RIE method to separate the respective elements. In such a manner, the photoelectric conversion element 601, the switching TFT 602, other wirings (606, 607, 609), and contact hole parts 610 are formed. Incidentally, it is also possible to form an electron injection inhibiting layer by changing the p<sup>+</sup>-layer, which is a hole injection inhibiting layer, to an n<sup>+</sup>-layer. That is the photoelectric conversion element comprises an insulating film which prevents both of the holes (the second carrier) and the electrons (the first carrier) from passing through and an injection inhibiting layer for inhibiting either one of the first and the second carriers from passing through.

Incidentally, FIG. 6 shows only elements for 4 pixels, however elements for a large number of pixels are simultaneously formed on the insulating substrate 603. Finally, in order to improve the moisture resistance, the respective elements and wirings are

coated with a passivation film (protective film) 615 of  $\text{SiN}_x$ .

As described above, the photoelectric conversion device of this embodiment is produced only by  
5 depositing the first metal thin film layer, the a-SiNx layer, the a-Si:H layer, the n<sup>+</sup>-layer and the second metal thin film layer on a whole plane, respectively, and etching the respective layers to commonly and simultaneously form the photoelectric conversion  
10 element, the switching TFT and the wirings.

In FIG. 7, a phosphor may be formed by directly depositing CsI on the protective film 615, or by, after GOS is formed in a sheet-like state in a separate process, sticking it using an adhesive.

15 By employing the above described processes using an amorphous silicon semiconductor as a main material, photoelectric conversion elements, switching elements, wiring for gate operation, and matrix signal wirings can simultaneously formed on the same substrate and a  
20 large surface area photoelectric conversion circuit part can easily and economically be provided.

FIG. 8 is a two-dimensional circuit diagram of the photoelectric conversion device illustrated in FIG. 1. In this circuit, only elements equivalent to  $3 \times 3 = 9$   
25 pixels are illustrated in order to simplify description. In the figure, the reference numeral 801 denotes a photoelectric conversion circuit part, 802 a

shift register (SR1), 803 a shift register (SR2), 804  
an operation amplifier, 805 an A/D conversion circuit,  
806A and 806B are d.c. power sources, 806I a diode, 807  
a circuit part for reading-out, and 808 a photoelectric  
5 conversion element.

The plan view and the cross-sectional view of the  
photoelectric conversion elements, the switching  
elements (TFT) and the like in FIG. 8 are the same as  
those shown in FIG. 6 and FIG. 7. A photoelectric  
10 conversion element has the same layer structure as that  
of the switching element and is composed as an MIS type  
capacitor. Incidentally, for the purpose of entering  
light rays in it, it is different from the normal MIS  
type capacitor in the point that an  $n^+$ -layer is used as  
15 an upper part electrode of the photoelectric conversion  
element. The photoelectric conversion element is a  
capacitor element as well and the signal charge  
generated by photoelectric conversion is accumulated in  
the capacity of itself.

20 Next, the description will be given regarding a  
method for carrying out operation such as accumulation  
of the charge of photoelectric conversion, transmission  
through the TFT, signal reading out, after completion  
of reset of a photoelectric conversion element, which  
25 is a capacitor, by using a bias circuit installed in  
the outer side, in this embodiment shown in FIGS. 1 to  
8. Further, the reset operation of the above described

photoelectric conversion element will be called as  
"refresh" hereafter. Incidentally, in FIG. 8, (S1-1)  
to (S3-3) are the above described photoelectric  
conversion elements, and "G" electrodes of the  
5 photoelectric conversion elements are the first metal  
thin film layer in FIG. 6, and "D" electrodes are the  
second metal thin film layer. Incidentally, as  
described above, the "D" electrodes as well as the n<sup>+</sup>-  
layer function as electrodes in the photoelectric  
10 conversion elements (S1-1) to (S3-3).

Next, the device operation of a photoelectric  
conversion element as a single body will be described.

FIG. 9A to FIG. 9C show the energy band diagrams  
for illustrating the device operation of the  
15 photoelectric conversion element as a single body.

FIG. 9A and FIG. 9B illustrate the operation  
states in the refreshing mode and the photoelectric  
conversion mode, respectively, in this embodiment and  
show the states in the film thickness direction of the  
20 respective layers shown in FIG. 7.

The reference symbol M1 denotes the lower part  
electrode (the G electrode) of a first metal thin film  
layer (Cr). The a-SiN<sub>x</sub> layer is an insulating layer for  
inhibiting both of electrons and holes from passing  
25 through and is necessary to be thick enough not to  
cause the tunnel effect and set to be 50 nm or thicker.  
The a-Si layer is a photoelectric conversion layer

formed as an i-layer of an intrinsic semiconductor.  
The  $n^+$ -layer is an injection inhibiting layer of an n-type a-Si layer formed so as to inhibit injection of holes to the a-Si layer. Further, the reference symbol  
5 M2 denotes the upper part electrode (the D electrode) of a second metal thin film layer (Al).

Although the D electrode does not completely cover the  $n^+$ -layer in this embodiment, since the electrons are made to be freely transmitted between the D electrode  
10 and the  $n^+$ -layer, the D electrode and the  $n^+$ -layer are always kept at the same potential and in the following description that is presumed.

The photoelectric conversion element of this embodiment is provided with two types of modes; the  
15 refreshing mode and the photoelectric conversion mode; by the voltage application methods to the D electrode and the G electrode.

In FIG. 9A (reflesh mode), negative potential is applied to the D electrode in relation to the G  
20 electrode, and holes denoted by a solid black circle (●) in an i-layer are led to the D electrode by an electric field. Simultaneously, electrons denoted by an open circle (o) are injected in the i-layer. At this time, a part of the holes and a part of the  
25 electrons are reconnected at  $n^+$ -layer and i-layer, respectively, and disappear. If such a state continues for an enough long time, the holes in the i-layer are

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swept out from the i-layer.

In order to convert the state (refreshing mode) shown in FIG. 9A to the state (photoelectric conversion mode) shown in FIG. 9B, positive potential is applied to the D electrode in relation to the G electrode. Consequently, electrons in the i-layer are led to the D electrode at once. However, holes are not led to the i-layer since the  $n^+$ -layer works as an injection inhibiting layer. In such a state, when light rays enter the i-layer, the light rays are absorbed and electron-hole pairs are generated. The electrons are led to the D electrode by an electric field and the holes move in the i-layer and reach the interface between the i-layer and the  $a\text{-SiN}_x$  insulating layer. However, the holes can not move to the insulating layer, they are accumulated in the i-layer. The electrons move to the D electrode and holes move to the interface with the insulating layer in the i-layer, so that current flows from the G electrode in order to keep the electrically neutral state in the photoelectric conversion element. The electric current corresponds to the electron-hole pairs and is proportional to the incident light rays.

When operation state is changed again to the state of FIG. 9A which is a refreshing mode after keeping the state of FIG. 9B which is the photoelectric conversion mode, the holes accumulated in the i-layer are led to



the D electrode as described above and simultaneously  
the current flows corresponding to the holes. The  
quantity of the holes corresponds to the total quantity  
of the light rays entering during the photoelectric  
conversion mode period. At that time, although  
electric current corresponding to the quantity of  
electrons injected to the i-layer, the quantity is  
approximately constant and therefore the detection may  
be carried out by subtracting the current by that  
extent. In other words, in this embodiment, the  
photoelectric conversion element outputs a quantity of  
incident light rays to at real time and at the same  
time detects the total quantity of light rays which  
enter the photoelectric conversion element during a  
certain period.

However, in the case where the period of the  
photoelectric conversion mode is long or the  
illuminance of the incident light rays is intense  
because of some reasons, sometimes no current flows in  
spite of entering of the light rays. The cause for  
that is that, as shown in Fig 9C, a large number of  
holes are accumulated in the i-layer and the electric  
field in the i-layer is reduced due to the holes and  
the generated electrons are thus not led and  
subsequently re-coupled with the holes in the i-layer.  
When the incident light state is changed in such a  
state, electric current sometimes flows unsteady,

however by changing to the refreshing mode again, the holes in the i-layer are swept and in the next photoelectric conversion mode, electric current in proportion to the light rays can flow again.

5 Further, in the above described description, when the holes are swept in the i-layer in the refreshing mode, it is ideal to sweep out all of the holes, however an effect can be obtained even by sweeping only a part of holes, and electric current equal to that in  
10 the case of entirely sweeping the holes can be obtained.

In other words, it is sufficient that the state at the time of the detection in the next photoelectric conversion mode is not the state shown in FIG. 9C, and  
15 the potential of the D electrode in relation to the G electrode in the refreshing mode and the period of the refreshing mode and the properties of the injection inhibiting layer of the  $n^+$ -layer may be determined so as to satisfy that. Further, in the refreshing mode,  
20 injection of the electrons in the i-layer is dispensable condition and the potential of the D electrode in relation to the G electrode is not necessarily limited to be negative. This is because in the case where a large number of holes are accumulated  
25 in the i-layer, even if the potential of the D electrode in relation to the G electrode is positive potential, the electric field in the i-layer is so

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generated as to lead the holes to the D electrode.  
Further, in the same manner, the properties of the  
injection inhibiting layer of the  $n^+$ -layer are not  
necessarily to be able to inject electrons to the i-  
5 layer.

Next, the operation of the photoelectric  
conversion device of this embodiment will be described  
according to the above described FIG. 8 and FIG. 10.

FIG. 10 is a timing chart showing the operation of  
10 the photoelectric conversion device of FIG. 8.

In FIG. 10, the control signal VSC is for applying  
two types of bias to the bias line REF of a  
photoelectric conversion element, that is, the D  
electrode of the photoelectric conversion element. The  
15 D electrode is at VREF (V) when VSC is "Hi" and at VS  
(V) when VSC is "Lo". The reference numerals 106A and  
106B denote d.c. power sources and they are a power  
source VS(V) for reading-out and a power source VREF  
(V) for refreshing, respectively.

20 At first, the operation during the refreshing  
period will be described.

The signals of the shift resistor 102 are all put  
in the "Hi" state to put the CRES signals of the  
circuit part for reading-out in the "Hi" state.  
25 Subsequently, all of TFT (T1-1 to T3-3) for switching  
are electrically communicated and the switching  
elements RES1 to RES3 in the circuit for reading-out

are also electrically communicated and the G electrodes of all of the photoelectric conversion elements are kept at GND potential. When the control signal VSC becomes "Hi", the D electrodes of all of the photoelectric conversion elements are put in biased state (at negative potential) by the power source VREF for refreshing. Consequently, all of the photoelectric conversion elements (S1-1) to (S3-3) are operated in the refreshing mode.

Next, the photoelectric conversion period will be described.

When the control signal VSC is switched to "Lo" state, the D electrodes of all of the photoelectric conversion elements are put in biased state (at positive potential) by the power source VS for reading-out. Subsequently, the photoelectric conversion elements are put in photoelectric conversion mode. In such a state, the entire signals of the shift registers 102 are put in "Lo" state and the CRES signals of the circuit part for reading-out are put in "Lo" state. Consequently, all of the TFT (T1-1 to T3-3) for switching are turned off and the switching elements RES1 to RES3 in the circuit for leading-out are also turned off and although the G electrodes of all of the photoelectric conversion elements are put in the open state in terms of d.c. current, the potential can be maintained since the photoelectric conversion elements

work also as capacitors.

However, at that time, since no light rays enter the photoelectric conversion elements, no electric charge is generated. In other words, no current flow.

5 In such a state, the light source is turned on by pulses (by a.c. current), light rays are radiated to the respective photoelectric conversion elements and so-called photocurrent flows. Regarding the light source, it is not particularly shown in FIG. 8, in the case of a copying machine, for example, a fluorescent lamp, LED, a halogen lamp, or the like are employed. In the case of an x-ray imaging apparatus, it is of course an x-ray source and a scintillator which becomes a wavelength converter for x-ray-visible light  
10 conversion may be employed. Further, semiconductors, which is directly sensitive to the radiation, for example GaAs and a-Se may be used. The photocurrent flowing by the light rays are accumulated in form of electric charge in the respective photoelectric  
15 conversion elements and maintained even after the light source is turned off.  
20

Regarding the reading-out period, the description is omitted since it is the same as described above.

After the refreshing period, the photoconversion  
25 period and the read-out period, one image can be obtained, and in the case of obtaining a plurality of images like a motion image, the above described

operation may be repeated. In this embodiment, since the D electrodes of the photoelectric conversion elements are connected in common and controlled to be at the potential of the power source VREF for refreshing and at the potential of the power source VS for reading-out by controlling the common wiring by the control signals VSC, all of the photoelectric conversion elements can simultaneously be switched to the refreshing mode and the photoelectric conversion mode. Therefore, without requiring complicated control, light output can be obtained with one TFT for one pixel.

In this embodiment, it is made possible to shorten the time taken to lower the dark current by lighting the second light sources installed in the outer casing during the non-reading-out period. Further, especially in a radiation detection apparatus, the exposure duration of the radiation source is better to be shorter and separate installation of the second light sources in such a manner is effective to shorten the time taken to lower the dark current without prolonging the exposure duration of the radiation source and therefore it is preferable to employ the second light sources.

(Embodiment 2)

FIG. 11 is a cross-sectional view showing Embodiment 2 of a photoelectric conversion device

according to the present invention. In FIG. 11, the reference numeral 1101 denotes an x-ray source, 1102 an object body to be read out, 1103 a chassis, 1104 a phosphor, 1105 a photoelectric conversion element, 1106 an insulating substrate, 1107 a protective layer, 1108 an LED, and 1109 is a photoconductor.

The different point from the photoelectric conversion device of the Embodiment 1 illustrated in FIG. 1, is that the photoconductor 1109 is installed under the photoelectric conversion substrate (the insulating substrate 1106) and LED 1108 as a second light source provided in the outer casing is arranged on the side face of the photoconductor 1109. The material for the photoconductor to be used is a transparent material such as acrylic resin, glass or the like whose refractivity is different from that of air.

FIG. 11 is a cross-sectional view showing the structure of the photoelectric conversion device, and photoelectric conversion elements are arranged in two-dimensional state in the depth direction of the sheet face of FIG. 11. The LED is also arranged in one-dimension state in the depth direction of the sheet face of FIG. 11. The light rays coming from the side face of the photoconductor 1109 proceed to the inside of the photoconductor. At that time, the light rays proceeding at an acuter angle than the critical angle

determined by the refractivity of the photoconductor 1109 and the refractivity of the ambient refractivity are full-reflected in the photoconductor interface and further proceed to the inside. On the other hand, the light rays proceeding at an obtuser angle than the critical angle are partially refracted and led to the photoelectric conversion substrate side. The radiation of the latter light rays at the time of non-reading-out can lower the dark current within a short time.

Although the upper face and the lower face of the photoconductor 1109 shown in FIG. 11 are drawn like planes, surface roughening processing can improve the diffusion property and the light rays coming out the photoelectric conversion substrate from the photoconductor are increased. The light rays coming out the insulating substrate side penetrate the side faces of the photoelectric conversion elements 1105, are reflected by the phosphor 1104 faces and reach the light-receiving faces of photoelectric conversion elements 1105. The photoelectric conversion device of this embodiment is made capable of shortening the waiting time without requiring installation of a second light source such as a large quantity of LED and without increasing the power consumption.

(Embodiment 3)

FIG. 12 is a cross-sectional view showing Embodiment 3 of a photoelectric conversion device



according to the present invention. In the figure, the reference numeral 1201 denotes an x-ray source, 1202 an object body to be read out, 1203 a chassis, 1204 a phosphor, 1205 a photoelectric conversion element, 1206 an insulating substrate working also as a photoconductor, 1207 a protective layer, and 1208 an LED.

In this embodiment, the insulating substrate in which the photoelectric conversion elements 1205 are arranged is used also as a photoconductor. The material for the insulating substrate working also as the photoconductor 1206 is a transparent material such as acrylic resin, glass or the like whose refractivity is different from that of air. FIG. 12 is a cross-sectional view showing the structure of the photoelectric conversion device and photoelectric conversion elements 1205 are arranged in two-dimensional state in the depth direction of the sheet face of FIG. 12. As the second light source installed in the outer casing, the LED 1208 is also arranged in one-dimension state in the depth direction of the sheet face of FIG. 12.

In FIG. 12, the light rays coming from the side face of the insulating substrate also working as a photoconductor 1206 proceed to the inside. At that time, the light rays proceeding at an acuter angle than the critical angle determined by the refractivity of

the insulating substrate also working as a  
photoconductor 1206 and the refractivity of the ambient  
refractivity are full-reflected in the lower face of  
the insulating substrate also working as a  
5 photoconductor 1206 and further proceed to the inside.  
On the other hand, the light rays proceeding at an  
obtuser angle than the critical angle are partially  
refracted and led to the photoelectric conversion  
substrate side. If the light rays are radiated to the  
10 photoelectric conversion element at the time of non-  
reading-out, the dark current can be lowered within a  
short time. Although the lower face of the insulating  
substrate also working as a photoconductor 1206 shown  
in FIG. 12 may be a flat face, if it is surface-  
15 roughened, the diffusion property is increased and the  
light rays coming to the side of the phosphor 1204 from  
the side of the insulating substrate also working as a  
photoconductor 1206 are increased. The light rays  
coming to the side of the phosphor 1204 penetrate the  
20 side faces of the photoelectric conversion elements  
1205, are reflected by the phosphor faces and reach the  
light-receiving faces of photoelectric conversion  
elements 1205. On the other hand, in the upper face of  
the insulating substrate also working as a  
25 photoconductor 1206, the light rays coming into  
collision to the first metal thin film layer of the  
photoelectric conversion elements 1205 (and the

switching elements) are reflected at a high ratio. Also, the light rays coming into collision to the protective layer 1207 other than the first metal thin film layer are reflected or refracted depending on the light proceeding conditions determined by the refractivity of the protective layer 1207 and the refractivity of the insulating substrate also working as a photoconductor 1206.

The photoelectric conversion device of this embodiment is made capable of shortening the waiting time without requiring installation of the second light sources such as a large quantity of LED and without increasing the power consumption. Further, the photoelectric conversion device can be light in weight and compact in size since the insulating substrate is used also as a photoconductor.

(Embodiment 4)

FIG. 13 is a cross-sectional view showing Embodiment 4 of a photoelectric conversion device according to the present invention. In FIG. 13, the reference numeral 1301 denotes an x-ray source, 1302 an object body to be read out, 1303 a chassis, 1304 a phosphor, 1305 a photoelectric conversion element, 1306 an insulating substrate working also as a photoconductor, and 1307 a protective layer.

In this embodiment, a plurality of light sources are not particularly installed and external light is

used in place of a light source in the outer casing. The outer casing is opened when the external light is taken in the photoconductor side and closed during the time other than that. The opening and closing may automatically be controlled by a motor. Since no space is required for installation of any light source in the outer casing, the apparatus can be miniaturized. Further, by properly selecting the motor, the electric power consumption can also be saved. This embodiment is especially effective in the case where the external light quantity is intense.

(Embodiment 5)

FIG. 14 is a cross-sectional view showing Embodiment 5 of a photoelectric conversion device according to the present invention. In FIG. 14, the reference numeral 1401 denotes an original document, 1402 a photoelectric conversion element, 1403 an insulating substrate, 1404 a protective layer, 1405 a chassis, and 1406 an LED.

The photoelectric conversion device according to this embodiment is a mode adapted to a copier or a facsimile reading an original document.

FIG. 14 is a cross-sectional view showing the structure of the photoelectric conversion device, and photoelectric conversion elements 1402 and LED 1406 are arranged in two-dimensional state in the depth direction of the sheet face of FIG. 14. Further,

although they are not shown in FIG. 1 of Embodiment 1, the photoelectric conversion elements 1402 and switching elements may be arranged in pairs on the insulating substrate 1403.

5           The light rays (visible light rays) emitted out the LED 1406 arranged under the insulating substrate 1403 are transmitted through the insulating substrate 1403, pass the side faces of the photoelectric conversion elements 1402, and reach the original  
10       document 1401, which is an object to be read out. Corresponding to the densities of the letters and the images drawn on the surface of the original document, the light rays are reflected by the original document face and radiated to the light-receiving faces of the  
15       photoelectric conversion elements 1402.

          The LEDs are turned on during both the reading-out periods and the non-reading-out periods. The lighting of the LED 1406 during the reading-out period is to read out the data of the original document by  
20       photoelectric conversion elements 1402. By lighting the LED during image-pickup and during the non-reading-out period, the dark current can be decreased during the reading-out period. Regarding the lighting of the LED during the non-reading-out period, the original  
25       document 1401 may be put or may not be put on the upper part of the photoelectric conversion elements and it is sufficient for some quantity of light rays to reach the

light-receiving faces of the photoelectric conversion elements 1402.

Depending on the raw materials of the original document itself or the ink, the original document has different reflective properties to light rays from the LED and any is acceptable unless it completely absorbs light rays and it is sufficient for the original document to reflect several % of light rays so as to reach the photoelectric conversion elements. Since there practically exist light rays coming from the diagonal direction, if components reflected by the mirror face of the original document face are included in the reflected light rays, the original document can never entirely absorb light rays. Further, in the case where no original document exists, the components of the light rays in the perpendicular direction from the LED do not reach the photoelectric conversion elements at a high ratio and since the refractivity of the protective layer and the refractivity of the ambient air differ from each other, the light rays from the diagonal direction from the LED and the light rays scattered by the edge parts of the metal thin film layers of the photoelectric conversion elements and the switching elements and emitted in the diagonal direction are partly reflected to the photoelectric conversion element side by the protective layer interface.

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(Embodiment 6)

FIG. 15 is a circuit diagram of photoelectric conversion element as one pixel showing Embodiment 6 according to the present invention.

5 A photoelectric conversion element 1503 shows a PIN type photo diode and usable as a material is possibly amorphous silicon, crystalline silicon, or the like.

10 The cathode side of the diode of a photoelectric conversion element 1503 is connected with an SW1 and the anode side is connected with an ammeter. The other side of the SW1 is made switchable to be connected either with a power source (Vs) for applying bias to the photoelectric conversion element or a zero bias  
15 (GND). The x-rays radiated from an x-ray source 1501, which is a first light source, are radiated to an object body to be inspected (a patient in the case of a hospital), which is not shown in FIG. 15, and the x-rays transmitted through the object come into collision  
20 to a phosphor 1502 which is an x-ray wavelength converter. The x-rays are converted to visible light rays by the phosphor 1502. The visible light rays from the phosphor 1502 are radiated to a photoelectric conversion element 503.

25 Since the circuit diagram of the photoelectric conversion element of this embodiment shown in FIG. 15 shows a circuit diagram only for one pixel, the

positioning correlation between the photoelectric conversion elements and the phosphor is therefore not illustrated. However, similarly as in Embodiment 1 illustrated in FIG. 1, the image resolution property is improved by practically closely attaching both of them to each other. On the other hand, the visible light rays from the LED light source 1504, which is a second light source, are radiated to the photoelectric conversion elements 1503 through another optical path different from that for the x-rays. SW2 and SW3 are switches for turning on the x-ray source 1501 and the LED light source 1504, respectively.

FIG. 16 is a timing chart of operation in the circuit of this embodiment shown in FIG. 15 and shows the x-ray source, the LED light source, bias of the photoelectric conversion element, and the output of the photoelectric conversion elements. In FIG. 18, the x-ray source and the LED dare not to be lighted in order to show the state of dark output (the dark current) of thes.

In the FIG. 18, when bias is applied to the photoelectric conversion element, the dark current flows in the photoelectric conversion element. It is preferable for the dark current to be ideally zero, however it is difficult to be zero. Further, constant electric current does not flow simultaneously with the time when the electric power source is turned on, but



the dark current is high immediately after the turning-on and gradually decays with the lapse of time.

Generally even in the case where the photoelectric conversion elements are fabricated using the PIN photodiode containing mainly an amorphous silicon semiconductor as a material, the dark current flows as described above.

Additionally, the blocking properties of a p-layer and an n-layer are not perfect and it is supposed that components for dark current are increased owing to the carriers flowing in the inside of an i-layer from the outside.

Further, in case of using a crystal type PIN-type photodiode without using an amorphous semiconductor film, it is said that the trap levels are not so many as compared with those in the case of using an amorphous semiconductor, although it depends on the process conditions and the apparatus to be fabricated. However, many crystal lattices are mismatched in the interface part between the p-layer and the i-layer and in the interface part between the i-layer and the n-layer and the trap levels are not zero, and there is a tendency of the output of the photoelectric conversion elements shown in FIG. 16.

A signal with a high S/N ratio can be obtained by waiting until the dark output (dark current) of the photoelectric conversion elements is sufficiently

decayed. However, it takes as long as several seconds to several ten seconds to decay the dark current to an aimed dark output level. In this case, for example, when the photoelectric conversion elements are employed for an x-ray imaging apparatus to be used in a hospital, the following procedure is required; a patient is guided to a photographing chamber, the photoelectric conversion elements are turned on, and after waiting for several to several ten seconds, the patient is subjected to x-ray exposure. Although it is better to turn on the electric power source for the photoelectric conversion elements before a patient comes in the photographing chamber, however in that case, deterioration (property change, corrosion, or the like) of the photoelectric conversion elements is accelerated to make it difficult to provide an apparatus with a long life.

FIG. 17 is a timing chart of the operation in the circuit of this embodiment illustrated in FIG. 15 and shows the case of lighting the LED light source after the electric power source of the photoelectric conversion elements is turned on.

By turning on the LED, photocurrent flows in the photodiode and finally, simultaneously with the time when the LED is turned off, the photocurrent is stopped. At that time, the dark current after the tuning off of the LED is stabilized with the lapse of

time or in some times lowered as compared with that in the case where the LED is not turned on (in the timing chart of FIG. 16). That is because the inner state (especially in the interface part) of a semiconductor layer is stabilized by excess carriers generated in the inside of the semiconductor layer by the photoenergy radiated by the LED and that either electrons or holes are released by the light radiation. If x-rays are radiated in such a low dark current state, signals with a high S/N ratio can be obtained.

In other words, an x-ray image with a high S/N ratio can be obtained without taking a long waiting time by lowering the dark current by radiating LED light before x-ray photography.

FIG. 18 is a timing chart showing the output situation of the photoelectric conversion elements when x-rays are turned on after the LED is turned on.

The LED is previously turned on in order to lower the dark current of the photoelectric conversion elements at the time when x-ray exposure is to be carried out within a short time. The photocurrent flowing at that time has nothing to do with the reading out of the image data. The period during which the LED is turned on is called as the non-reading-out period.

On the other hand, x-rays are radiated only for reading-out the internal data of a patient. The period during which x-rays are radiated is called as the

reading-out period. The light rays of the LED (the second light source) are radiated during the non-reading-out period, and x-rays (the first light source) are radiated during the reading-out period. The duration of the non-reading-out period and the reading-out period or the radiation duration of the LED may be determined depending on the properties of the dark output (the dark current) of the photoelectric conversion elements and the S/N ratio required for the photoelectric conversion device.

(Embodiment 7)

FIG. 19 is a block diagram of a photoelectric conversion device of Embodiment 7 according to the present invention. In the block diagram of FIG. 19, illustrated is the schematic diagram of an image processing system using an x-ray imaging apparatus to be employed in a hospital. In FIG. 19, the reference numeral 1901 denotes an x-ray source, 1902 a patient, 1903 a photoelectric conversion element, 1904 an x-ray-visible light converting phosphor, 1905 a protective layer, 1906 a substrate, 1907 an LED, 1908 control means, 1909 a timing generation apparatus, and 1910 a plurality of driving signals.

In FIG. 19, radiation, for example, x-rays radiated from an x-ray source are radiated to the patient 1902 and the x-rays transmitted through the patient reach the x-ray imaging (image-pikup)

apparatus. The x-rays are converted to visible light rays by the phosphor which is a wavelength converter, and the visible light rays are radiated to the photoelectric conversion elements 1903. The visible  
5 light rays contain the image data of the patient 1902. The photoelectric conversion elements 1903 and the wavelength converter are practically closely attached to each other and in FIG. 19, they are closely attached through the thin protective film 1905. Further, the  
10 photoelectric conversion elements 1903 are installed on the substrate 1906. A light source is installed on a side opposite to the light-receiving face side of the photoelectric conversion elements 1903 on the substrate 1906. In this case, the LED are used as the light  
15 source. The light rays from the LED 1907 are transmitted through the substrate 1906 and reflected by the wavelength converter and then reach the photoelectric conversion elements 1903.

The radiation (switching on) of x-rays and  
20 lighting (switching on) of the LED light source and switching off are controlled by control means.

In FIG. 19, only the photoelectric conversion elements are illustrated, a switching element may be installed just like the 2-dimensional circuit diagram  
25 as shown in FIG. 8. Further, in FIG. 19, only the photoelectric conversion elements installed on the substrate are illustrated, however the photoelectric

conversion circuit part 801 and the circuit part for  
reading-out 807 as shown in FIG. 8 are installed. The  
photoelectric conversion circuit 801 and the circuit  
part for reading-out 807 are operated by signals based  
5 on the timing chart shown in FIG. 10. These signals  
are VSC, REF, CRES, G1, G2, G3, SMPL, Sr1, Sr2, Sr3 or  
the like. They are outputted by a timing generation  
apparatus and inputted to the photoelectric conversion  
device (801 and 807 shown in FIG. 8). In other words,  
10 the signals from the timing generation apparatus  
operate the photoelectric conversion device. As shown  
in FIG. 19, the timing generation circuit is controlled  
(ON/OFF) by the control means. As an example of  
constitution of the control means, a computer is  
15 available. The control mean independently control the  
x-ray source, the photoelectric conversion device, and  
the LED which are a second light source, and if a  
computer is employed for the control means, the control  
method can be programmed by a software. That is, the  
20 handling convenience can be improved and consequently,  
the added value as the x-ray imaging apparatus to be  
used in a hospital is increased.

Further, also possible is a method which comprises  
installing the A/D conversion circuit part 805 shown in  
25 FIG. 8, which is not shown in FIG. 19, in the periphery  
of the photoelectric conversion circuit part 801 and  
the circuit part for reading-out 807 and storing the

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digital data of the A/D conversion circuit part 805 in  
the memory of the computer (the control means).

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